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The Study on Mechanical Reliability Design Method and Its Application

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Abstract

Based on the reliability test and statistical analysis of the failure data, the basic task of mechanical reliability design is to propose mathematical-mechanical models and methods for engineering practice. In this way the working state and life of the mechanical product under the prescriptive working condition can be predicted in the design stage. The connotation and development of mechanical reliability-based design is expounded by integrating modern mathematical-mechanical theories. A series of theories and approaches, such as the mechanical reliability-based design, dynamic reliability-based design, reliability-based optimization design, reliability-based sensitivity design, reliability-based robust design, are explained clearly and systematically. Based on characteristics of mechanical reliability design, as well as study on reliability design of mine hoist, taking mine hoist spindle bearing as example, this paper discusses the application of reliability design in mine hoist design.

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1. Introduction

The increasing development of science and technology has made greater requirements of products, which should be of not only better performance, but also higher reliability. On the basis of traditional designs, the reliability design processes such parameters as material properties, dimension of parts, loads, strength and others to be random variables that comply with certain statistical law. Besides, mathematical probability model and its distribution will be formed according to this design rule. By virtue of probability and statistics theories and strength theory, the formula of probability for parts' damage under given conditions is also to be obtained and thereby their dimension and life under given reliability will be calculated, which both satisfies the operation requirements and helps with the formation of optimal design parameters[1], or the reliability of parts and system can be concluded according to the reliability design theory. Therefore, the design mentioned above makes up for the disadvantages of the conventional designs and reduces the distance between design program and production practice.

2.The Development Status of Reliability Optimization Design of Mechanical Products

The reliability-based optimization design has become an important branch of optimization design. Used in the mechanical parts - gear, gear reducer. China has been the reliability-based optimization design of gear transmission and the reliability-based optimization design of planetary gear transmission, etc. In the reliability of communication problem, radar, and other aspects of the machines have been put forward in China in the 1960s. With the rapid economic development and reform and opening in the late 1970s propulsion system reliability of key components of use and civil items. After years of efforts, the reliability of military components has two orders of magnitude. In the 1980s, a group of researchers and technical backbone of the reliability of the organization, established in China, further implementation of state ministries of reliability engineering has begun. In 1990, China's civil and military products with a qualitative leap, many civil electrical products, has made such a reliability of the product quality has reached a new high.

In the past 30 years, optimization design method, the rapid development of mechanical products, especially in the development of the reliability design of mechanical products, technology and practical in engineering practice of mechanical products. People think that the optimal design of mechanical products reliability is more reasonable basis, because in traditional mechanical products than by as a whole, the performance of randomness, in the future work. That is to say, some parameters of the simulation of mechanical products as random variables, in structure optimization design based on reliability, the reliability requirements of integration of mechanical products for optimization design of the constraint conditions, or into our target function optimization design, namely, in certain reliability index weight, reduce the cost of mechanical products, or by adjusting the parameters of mechanical products, or under certain conditions, the maximum weight and cost of mechanical products by adjusting the parameters, the reliability of the parts. The main requirements of mechanical products are not only safe, reliable and economical rationality. Therefore, the optimization design of mechanical products, can significantly improve the design quality and economic benefit, the reliability design of mechanical products has become an important problem in the empirical research and exploration in the domestic and foreign current. However, due to mechanical product reliability analysis is related to large amounts of invalidation forms and other relevant problems of failure modes, reliability more difficult, more and more complex, therefore, the reliability design of mechanical products is becoming more difficult. In addition, the optimal solution algorithm was used to optimize the design, is also discussed. Therefore, the current level of reliability and optimal design of mechanical products is still in the early stages of development [1].

3.The Advantages of High Reliability Mechanical Products

3.1. *Improve the Usage Rate of Product*

To improve the reliability of mechanical products, reduce downtime and maintenance personnel, improve product utilization. Modern machinery products work environment become more severe, and from the land, sea and provide a harsh environment space challenge, high reliability, high safety and the characteristics of the system, system integration and other needs to continue for a long time without forcing the system must have a good reliability.

3.2. *Prevent the Occurrence of Accidents and Failures*

To improve the reliability of mechanical products, it can prevent accidents and failure, especially in order to avoid catastrophic accidents. The 1986 challenger space-shuttle is America's seal failure, after take-off, explosion 76 seconds. The economic loss caused by 120 million dollars. Modern high-tech product, because its strict function.

3.3. Obvious Technology and Economic Benefits

Mechanical reliability and optimal design is based on probability theory and optimization design method, the application of participation mechanism design, strength, and the design, material selection and life failure analysis, and many other design variables and parameters, and provide clear technology. And the economy and reliability index also exists, the objective function optimization model and the characteristics of probability and nonlinear, non-convex nonlinear, need to meet all kinds of random constraints. Mechanical product design method, according to the work product can not only ensure the reliability and safety of the product, the function, the weight, small volume, cost and other parameters are optimized, technical and economic benefits have been markedly improved.

4. Reliability Optimization Design of Mechanical Products

This puts forward the problem of reliability optimization design. Reliability optimization design mainly considers the following questions:

- With optimum design, can according to different design requirements, choose different characteristic function as the objective function.
- Design variables. The overall size of the structure and size of components and mechanical properties, etc, are the most common design variables of mechanical components, is needed to optimize and final independent parameters optimized design process. In the determination of design parameters of the randomness and distribution parameters should be regarded as reflect the actual conditions of the parts.
- Constraint conditions. Constraint conditions can be restrictions not only on structural parameters, but also on a function of parts, this need refer to the conventional optimal design, according to the specific circumstances to determine.

In the meeting reduce the requirement of reliability, or in the meeting of the total cost of cost, the value of size, weight and other indicators, the maximum reliability. Therefore, the reliability design of mechanical products can be divided into two types of the mathematical model of optimum reliability design.

- Reliability as the objective function.
- Reliability as a constraint condition

5. The Design Features of Mechanical Parts

5.1. Stress and Strength Are Random Variables

Because the stress that parts can support and materials' strength are not certain values but random variables with discreteness, distribution function is taken into account in mathematics. It's because loads, strength, dimension and operation have the characteristics of alternativeness and statistical property [2], and thus probability and statistics theories are needed to analyze and solve the problem.

5.2. Quantitative Description of Products' Failure Probability and Reliability Can Be Done

As is known, the designed products have certain failure probability, which can not be above the permissible value stated in the technical documents. However, the reliability design can provide products' failure probability and reliability quantitatively.

5.3. Various Reliability Indexes Can Be Chosen

The traditional design has only one evaluation index for reliability, namely, safety coefficient. By contrast, the reliability design provides various and appropriate indexes according to the specific conditions for different products, such as failure probability, reliability, non-failure working time on average, first-failure driving miles(for vehicles), maintainability, availability and so on.

5.4. The Effect of Environment Is Taken into Consideration

Owing to the great influence on stress of the following surroundings factors such as temperature, impact, quake, moisture, mist, erosion, dust, and abrasion, reliability is considerably affected consequently. And thus taking environment into consideration can reflect parts' actual operation better

6. The Reliability Design Principles of Mechanical Products

Compared with electric products, mechanical products have their own characteristics and ways of design and analysis. To sum up, the reliability design of mechanical products should stick to the principles as follows [3, 4]:

6.1. Combination of Reliability Design and Traditional Design

The traditional safety coefficient method which is intuitive, simple and easy to master and has a small workload can ensure the reliability of mechanical parts under most circumstances. But at present it is very difficult to carry out traditional reliability design of mechanical products in special cases. For this reason, it seems reasonable and necessary to improve and perfect the traditional method with the help of probability design. Moreover, the reliability probability design aimed to crucial parts can be gradually performed

6.2. Integration of Quality and Quantity Design

Quantity design refers to the quantity analysis and calculation of reliability, but it can not solve all the problems concerned with reliability. What's more, at some times, it is inappropriate and even impossible for reliability to expound quantitatively. And thereby the reliability requires the integration of the quality and quantity. As for the parts which have the quality requirements and are difficult to make quantity calculation, it is more reasonable and effective to conduct quality design. Practice has proved that the quality design plays an important role in assuring and improving the reliability of mechanical products. And thus during the process of reliability design, quality and quantity design should be integrated.

6.3. Paralleling of Mechanical Reliability and Durability

In a broad sense, the reliability of mechanical products includes reliability and durability. Therefore, mechanical reliability design accordingly comprises the two mentioned above. Specifically speaking, reliability design is specific to occasional faults, while durability is specific to gradual faults, and their fault mechanism are different.

6.4. Paralleling of System and Parts Reliability

Given that mechanical parts are of lower standardization and universality degree and have complex functional status and structure, the designers have to make a comprehensive design of system and parts. The parts strength is basic guarantee of systematic reliability and parts are the most basic unit of the whole system. In this case, parts' design should add reliability design to the traditional one. The aim of systematic

reliability design is to achieve the coordination and optimization of technical performance, weight index, manufacturing cost and service life of the system, providing that the system has satisfied the established reliability index and realized predetermined functions.

7.The Allcation of Reliability Design in Mine Hoist

The key to the reliability design in mine hoist is how to change equipments at present and parameters concerned (for instance the parts' dimension, strength and loading) into statistics through experimental data and finally conclude its distribution. Furthermore, the reliability, dimension and life service can also be calculated one after one.

The decelerator and spindle structure in the hoist are equipped with rolling bearing, whose life span has a vital impact on the operation reliability of the hoist. Now that the cycle times of rolling bearing during the lease of life can reach up to and even exceed the cycle base of material fatigue limit (about 10^7). It is common to adopt limited life design in order to rationalize the whole structure, reduce its dimension and weight, and at last make the best of materials and improve the bearing capacity of parts. On the condition that cycles is 10^6 and reliability is 90%(namely, with the help of equal load of dynamic load rating C, the rolling bearing can run 10^6 runs, and in the meanwhile 90% of the bearing does not suffer from fatigue pitting failure [5])the design and choice of bearing capacity is executed.

On the basis of the previous analysis, the reliability design of rolling bearing in spindle structure is to be made.

The rolling bearing stands vice-varying stress. The failure in the course of operation results from the regular changes of the stress. Because of the long-term effect of the stress, the surface metals fall down from both rolling body and inner and outer raceways. Fatigue pitting comes into being and also leads to fatigue failure. It is proved that the life span of the original and device or equipments, of all whose functions have failed due to partial fatigue failure or fault, is in line with Weibull distribution. So is that of rolling bearing. The failure probability F can be described as:

$$F(N) = 1 - \exp \left[- \left(\frac{N}{N_a} \right)^m \right] \quad (1)$$

In the above, N_a stands for characteristic life; N for cycles, with 10^6 as the unit; m for the parameter.

Reliability can be formulated as:

$$R(N) = 1 - F(N) = \exp \left[- \left(\frac{N}{N_a} \right)^m \right] \quad (2)$$

After logarithm operation on both sides:

$$N = N_a [-\ln R(N)]^{1/m} \quad (3)$$

Based upon the preceding analysis, the rated life of rolling bearing is L_{10} (that is, the failure probability is 10%) when the reliability is 90%. Thus the rated life is

$$L_{10} = N_0 = N_a [-\ln R(90)]^{1/m} = N_a [-\ln 0.9]^{1/m} \quad (4)$$

In the above, N_{90} refers to the cycles when the reliability is 90%.

Divide (3) by (4), the result becomes:

$$N = L_{10} \left[\frac{\ln R(N)}{\ln 0.9} \right]^{1/m} \quad (5)$$

Large quantities of statistics indicate: the ball bearing: $m = \frac{10}{9}$; the roller bearing: $m = \frac{3}{2}$; the roller bearing of the cone: $m = \frac{4}{3}$

For example, there is a friction hoist JKD 2.8×6 in a mine. The life of its main bearing (Model 3676) with 90% reliability is 1,000,000 rpm. And then the bearing life with 93% reliability is:

$$N = L_{10} \left[\left(\frac{\ln 0.93}{\ln 0.9} \right)^{1/4} \right] = 756,000 \text{rpm}$$

8. Conclusion

Through the study on mechanical reliability design and combination with the structure of mine hoist, it is proposed that the crucial procedure of reliability design's application into mine hoist is as follows. The first is to ascertain the statistics of the relevant parameters, then to set up the failure mathematical model, and finally the reliability design can be operated. Besides, the rolling bearing of mine hoist is regarded as the object of this study, meanwhile bearing's fatigue life as statistics, from which the rule that bearing's life accords with Weibull distribution is learned. Next, based on the result that the rated life of rooling bearing is L_{10} (that is cycle) when the reliability is 90%, the bearing's life (cycle) is calculated according to the given reliability. In a word, it is extremely meaningful for the improvement of hoist's reliability when the theoretical knowledge about mechanical reliability design is applied into the design of mine hoist' parts.

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